Influence of the main cereal and feed form of the rearing phase diets on performance, digestive tract, and body traits of brown-egg laying pullets from hatch to 17 weeks of age[1]

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ABSTRACT The effects of the main cereal and feed form of the rearing phase diets on growth performance, gastrointestinal tract characteristics, and body traits were studied in brown-egg pullets from hatch to 17 wk of age. Eight dietary treatments that were a combination of 2 main cereals (corn vs. wheat) and 4 feeding programs were used. The feeding program consisted in feeding crumbles from 0 to 5, 0 to 10, or 0 to 17 wk of age followed by mash until 17 wk, or feeding mash continuously from 0 to 17 wk. Each treatment was replicated 9 times. From hatch to 17 wk of age, pullets fed corn had similar ADG but poorer feed conversion ratio (FCR; $P < 0.001$) than pullets fed wheat. Also, pullets fed crumbles continuously (0 to 17 wk) had greater ADG (12.3 vs. 11.5 g; $P < 0.001$) and better FCR (4.21 vs. 4.36; $P < 0.001$) than pullets feed mash continuously, with pullets that were changed at any age of the rearing period from crumbles to mash feeding showing intermediate results. At 17 wk of age, the relative weights (% BW) of the gastrointestinal tract and gizzard were greater in pullets fed corn than in pullets fed wheat ($P < 0.01$) but the relative length (cm/kg full BW) of the small intestine, body, and tarsus was not affected. Pullets fed crumbles continuously had lighter gizzards ($P < 0.001$), higher gizzard pH ($P < 0.001$), and were shorter ($P < 0.01$) than pullets fed mash continuously, with pullets fed the other 2 treatments being intermediate. In summary, wheat can be used in substitution of corn in pullet diets without any adverse effect on growth performance. Feeding crumbles improves pullet performance but hinders gizzard and gastrointestinal tract development. Growth performance, gastrointestinal tract, and body traits of the pullets re-adapt quickly to changes in feed form of the rearing diets.

Key words: corn, crumbles, gastrointestinal tract development, mash, wheat

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INTRODUCTION

Dent corn (*Zea mays* L.) and soft wheat (*Triticum aestivum* L.) are the most common cereals used in poultry diets. Because of differences in growing and storage conditions, and nonstarch polysaccharides (**NSP**) content, the nutritive value of wheat is more variable than that of corn (Kim et al., 1976; Mollah et al., 1983; Gutiérrez-Álamo et al., 2008) and consequently its use in diets of young birds is limited (FEDNA, 2010). In addition, corn has on average less protein (7.7 vs. 10.2%) but more energy (3,260 vs. 3,100 kcal AME_n/kg) than wheat (FEDNA, 2010). Several researches have compared diets based on corn or wheat in broilers (Crouch et al., 1997; Mathlouthi et al., 2002; Masey-O'Neill et al., 2014), pullets (Frikha et al., 2009a, 2011), and laying hens (Lázaro et al., 2003a; Safaa et al., 2009; Pérez-Bonilla et al., 2011). In most cases, the authors concluded that wheat can be used in substitution of corn without any effect on performance, provided that the feed is supplemented with NSP enzymes. However, Frikha et al. (2009a) reported a 1.5% reduction in ADG in pullets fed wheat with NSP enzymes as compared with pullets fed corn from 0 to 17 wk of age, although no differences in feed conversion ratio (**FCR**) were detected. Also, these authors observed that at 6 wk of age the gizzard was lighter in pullets fed wheat than in pullets fed corn.

Hens that are light at the initiation of the laying period produce less eggs that are smaller during the whole cycle than hens that are heavy (Leeson et al., 1997; Pérez-Bonilla et al., 2012a,b). The use of crumbles during the rearing phase might be a sound nutritional strategy for improving BW of the hens at the onset of egg production (Frikha et al., 2009b; Saldaña et al., 2015). Under commercial conditions, broilers are frequently fed crumbles for the first 2 to 3 wk of life and then pellets until slaughter, a practice that results usually in improved ADG and FCR (Amerah et al., 2007a; Abdollahi et al., 2013a; Serrano et al., 2013).

Similar results, although of less magnitude, have been reported in pullets (Guzmán et al., 2015; Saldaña et al., 2015). Frikha et al. (2009b) observed that ADFI and ADG were greater in pullets fed pellets from 0 to 6 wk and then mash to 17 wk of age, than in pullets fed mash continuously from hatch to 17 wk of age. Serrano et al. (2012) showed that some of the benefits of feeding crumbles to broilers during the prestarter phase disappeared when the broilers were fed a pelleted diet until slaughter. The authors have not found any report on the effects of the main cereal of the diet and the duration of feeding crumbles, on productive performance and gastrointestinal tract development of brown-egg pullets during the entire rearing period.

We hypothesize that pullets could respond similarly, independent of feed form, to the feeding of diets based on corn or wheat supplemented with adequate NSP enzymes. Also, pullets would quickly adapt their gastrointestinal tract and modify productive performance accordingly, when switched from crumbles to mash feeds. The aim of this research was to evaluate the effects of feeding crumbles for different periods of time, followed by feeding mash to 17 wk of age, on performance, gastrointestinal tract development, and body measurements of brown-egg laying pullets fed diets based on corn or wheat.

MATERIALS AND METHODS

Husbandry

The experimental procedures used in this research were approved by the Animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007).

In total, 3,600 one-day-old Lohmann Brown Classic pullets were used in this experiment. On arrival at the experimental farm, pullets were weighed individually and distributed at random into groups of 50 into 72 cages. Because of the dimensions (80 cm × 68 cm × 40 cm) and equipment of the cages, 27 to 28 pullets of each cage (depending on previous mortality) chosen at random, were discarded at 3 wk of age. Consequently, only 22 pullets formed the experimental unit after 3 wk of age. Pullets were beak-trimmed at 8 d of age, vaccinated against the main diseases (Infectious Bronchitis Disease, Marek Disease, Infectious Bursal Disease, Newcastle Disease, and *Salmonella spp.*), and managed according to accepted commercial practices (Lohmann, 2013). The environmental conditions during the experiment were controlled automatically according to the age of the birds. Room temperature was maintained at 32°C during the first 3 d of life and then was reduced gradually until reaching 24°C at 6 wk of age. The light program consisted of 24 h of light for the first week, and then light was decreased 2 h per week until reaching 12 h at 7 wk of age. From 7 wk of age to the end of the experiment, pullets were exposed to a constant light period of 12 h.

Feeding Program, Diets, and Experiment Design

The feeding program consisted of 3 diets supplied from 0 to 5 wk, 5 to 10 wk, and 10 to 17 wk of age. Within each period, the diets had similar nutrient content (FEDNA, 2010) and met or exceeded the nutritional recommendations of FEDNA (2008) for pullets (Table 1). All diets were supplemented with a commercial enzyme complex with xylanase and β-glucanase activity (Roxazyme, DSM S.A., Madrid, Spain). In the formulation of the diets, it was assumed that the inclusion of the NSP enzyme complex increased the energy content of the wheat by 2% (from 3,100 to 3,162 kcal AME_n/kg) but that the energy content of all the other ingredients were not affected (FEDNA, 2010). For the manufacturing of the diets, the cereals were ground to pass through a 4 or 5 mm screen for feeds used from 0 to 5 wk and from 5 to 17 wk of age, respectively. Within each of the 3 feeding periods, feed batches were divided into 2 portions; the first portion was used as it was, and the second portion was steam-conditioned at 72°C for 60 s, pelleted using a 3 mm screen (Model PVR 180 2T, Mabrik, Barcelona, Spain), and crumbled.

The experimental design was completely randomized with 8 treatments arranged as a 2 × 4 factorial with 2 cereals (corn vs. wheat) and 4 feeding programs that consisted in feeding crumbles or mash continuously from hatch to 17 wk of age, or changing the feed form from crumbles to mash at 5 or 10 wk of age.

Laboratory Analyses

Representative samples of the diets were ground in a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) fitted with a 1 mm screen and analyzed for moisture by oven-drying (method 930.01), ash by a muffle furnace (method 942.05), and nitrogen by combustion (method 990.03) using Leco equipment (model FP-528, Leco Corporation, St. Joseph, MI) as described by AOAC International (2005). Gross energy was measured using an adiabatic bomb calorimeter (model 356, Parr Instrument Company, Moline, IL). Ether extract was analyzed after 3 *N* HCl acid hydrolysis (method 159 Am 5–04) as indicated by AOCS (2004) using an Ankom XT10 Extraction system 160 (Ankom Technology Corp. Macedon, NY). Calcium and P were determined by spectrophotometry (methods 968.08 and 965.17) as described by AOAC International (2005). Particle size distribution and the geometric mean diameter (**GMD**) of the mash and crumble diets were determined in 3 subsamples of 100 g each using a shaker (Retsch, Stuttgart, Germany) provided with 8 sieves ranging in mesh from 5,000 to 40 μm, as indicated by

Table 1. Ingredient composition and calculated nutritive value of the experimental diets[1] (% as fed basis, unless otherwise indicated).

Item	0–5 wk		5–10 wk		10–17 wk	
	Corn	Wheat	Corn	Wheat	Corn	Wheat
Ingredient						
Dent corn	40.0	–	40.0	–	40.0	–
Soft wheat	–	40.0	–	40.0	–	40.0
Soybean meal (46% CP)	34.2	31.7	18.5	15.6	12.3	9.3
Barley	13.0	17.0	24.1	27.0	20.0	22.8
Wheat middling	–	–	–	–	12.0	12.0
Sunflower meal (28% CP)	5.97	4.54	12.70	12.80	11.52	11.64
Soybean oil	2.71	2.92	1.00	0.90	1.00	1.00
Dicalcium phosphate	2.07	2.04	1.21	1.15	0.88	0.70
Calcium carbonate	1.04	0.82	1.40	1.40	1.36	1.56
Sodium chloride	0.35	0.35	0.35	0.35	0.35	0.35
L-Lys-HCL (78%)	–	–	0.13	0.20	0.03	0.08
DL-Met (99%)	0.16	0.13	0.11	0.10	0.06	0.07
Vitamin and mineral premix[2]	0.50	0.50	0.50	0.50	0.50	0.50
Calculated analysis[3]						
AME_n (kcal/kg)	2,790	2,790	2,700	2,700	2,650	2,650
Crude fiber	4.7	5.3	6.2	6.4	6.3	6.6
CP	21.5	21.8	18.0	18.0	16.0	16.0
Ether extract	5.2	4.6	3.5	2.7	3.7	2.9
Total ash	6.2	6.2	5.4	5.4	5.4	5.4
Digestible AA						
Arg	1.30	1.34	1.05	1.05	0.92	0.89
Lys	0.97	0.97	0.79	0.79	0.60	0.60
Met	0.45	0.43	0.37	0.35	0.30	0.30
Met + Cys	0.74	0.74	0.62	0.62	0.53	0.53
Thr	0.68	0.68	0.54	0.53	0.47	0.45
Trp	0.22	0.24	0.18	0.19	0.16	0.17
Calcium	0.95	0.95	0.90	0.90	0.85	0.85
Phosphorus	0.78	0.80	0.63	0.63	0.62	0.60
Digestible phosphorus	0.45	0.45	0.42	0.42	0.40	0.40

[1]Diets were offered either as mash or crumbles, according to treatment.

[2]Provided the following (per kilogram of diet): vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D3 (cholecalciferol), 3,000 IU; vitamin E (all-rac-tocopherol-acetate), 30 mg; vitamin K3 (bisulphatemenadione complex), 3 mg; riboflavin, 8 mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (dicalcium pantothenate), 15 mg; folic acid, 1.5 mg; D-biotin, 0.2 mg; thiamin (thiamine-mononitrate), 2 mg; vitamin B_{12} (cyanocobalamin), 25 μg; Se (Na_2SeO_3) 0.2 mg; I (KI), 2 mg; Cu ($CuSO_4$ $5H_2O$), 8 mg; Fe ($FeCO_3$), 60 mg; Mn (MnO), 70 mg; Zn (ZnO), 80 mg. Roxazyme [1,600 IU endo-1,4-β-glucanase (EC 3.2.1.4), 5,200 IU endo-1,3(4)-β-glucanase (EC 3.2.1.6), and 5,200 IU endo-1,4- β-xylanase (EC 3.2.1.8)], 200 mg; Natuphos 5000 [400 FTU/kg 6-phytase (EC 3.1.3.26) Basf Española S.A, Tarragona, Spain], 80 mg.

[3]According to FEDNA (2010).

ASAE (1995). All of the analyses were conducted in duplicate, except for the GMD of the diets which were determined in triplicate. The determined chemical analysis and the GMD of the experimental diets are shown in Table 2.

Growth Performance

Individual BW of the pullets and feed disappearance per replicate were measured at 5, 10, and 17 wk of age, and mortality was recorded and weighed as produced. These data were used to calculate ADG, ADFI, FCR, and BW uniformity by period, and for the entire experiment. Body weight uniformity was determined as indicated by Peak et al. (2000). Briefly, the CV of the individual BW within each cage was generated and this variable was used to estimate BW uniformity of the pullets at each particular age.

Gastrointestinal Tract Traits and Body and Tarsus Length

At each of the 3 growth performance control periods (5, 10, and 17 wk of age), 2 birds per replicate were randomly selected, weighed individually, and slaughtered by CO_2 asphyxiation. The gastrointestinal tract (**GIT**), from the beginning of the proventriculus to the cloaca, including the digesta content, and the spleen, liver, and pancreas, were removed and weighed, and the GIT weight expressed relative to BW (**RW**, % BW). Then, the gizzard was excised and the pH of its contents was measured in situ using a digital pH meter fitted with a fine-tip glass electrode (model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jiménez-Moreno et al. (2009). The full gizzard was weighed, emptied of any digesta content, cleaned, dried with desiccant paper, and weighed again, and the gizzard content was estimated by difference. The weight of the

Table 2. Chemical analyses (% as fed basis, unless stated otherwise), particle size distribution (%), and geometric mean diameter (GMD, μm) of the experimental diets.[1]

	0–5 wk				5–10 wk				10–17 wk			
	Corn		Wheat		Corn		Wheat		Corn		Wheat	
Item	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash	Crumble	Mash
GE[2] (kcal/kg)	4,000	3,970	4,075	3,995	3,931	3,931	3,881	3,890	3,952	4,038	3,951	4,015
DM	91.7	91.0	91.4	91.1	91.7	91.7	91.2	91.2	90.8	91.6	90.7	91.2
CP	20.5	20.4	20.6	20.7	17.8	18.1	17.4	17.5	15.4	15.7	15.9	16.2
Ether extract	5.1	5.3	5.0	5.2	3.6	3.6	2.8	3.1	3.4	3.6	3.0	3.3
Total ash	6.7	6.6	6.0	6.5	5.9	6.1	6.5	6.3	6.2	6.3	6.4	6.7
Calcium	1.0	1.1	1.0	1.0	0.9	0.9	1.0	1.1	1.0	1.1	0.9	0.9
Phosphorus	0.83	0.87	0.83	0.79	0.72	0.70	0.71	0.65	0.68	0.65	0.66	0.68
Particle size[3]												
>2,500	9.3	7.6	10.4	6.7	22.8	23.0	28.6	16.2	17.8	23.1	20.2	19.0
1,250	51.3	27.7	53.9	29.6	61.2	30.2	51.5	39.0	65.2	29.0	57.9	36.7
630	26.2	23.0	21.6	21.6	12.4	26.1	13.2	26.5	14.6	26.4	15.5	24.0
315	8.7	16.5	6.6	27.7	2.3	10.9	3.2	11.1	1.7	13.5	3.4	11.5
160	2.8	10.1	6.0	11.4	0.5	7.4	2.0	5.0	0.5	7.5	1.1	6.0
<80	1.5	2.1	1.3	2.8	0.3	2.1	1.0	2.0	0.3	1.4	1.2	2.0
GMD ± GSD[4]	1,255 ± 2.0	735 ± 2.6	1,295 ± 2.0	799 ± 2.3	1,792 ± 1.7	1,204 ± 2.4	1,741 ± 2.0	1,204 ± 2.2	1,734 ± 1.6	1,191 ± 2.4	1,645 ± 1.9	1,199 ± 2.3

[1]Analyzed in duplicate samples.

[2]Gross energy.

[3]The percentage of particles bigger than 5,000 μm or smaller than 40 μm was negligible for all diets.

[4]GSD = Log normal SD.

full gizzard was expressed relative to BW and that of the digesta content relative to full organ weight. The length of the duodenum (from the gizzard to the pancreo-biliary duct), jejunum (from the pancreo-biliary ducts to Meckel's diverticulum), ileum (from Meckel's diverticulum to ileo-cecal junction), small intestine (**SI**; duodenum, jejunum, and ileum), and the 2 ceca (from the ostium to the tip of the right and left ceca) were also determined, and expressed relative to BW (**RL**, cm/kg BW).

Before removing the GIT, the length of the pullets, from the tip of the beak to the end of the longest phalanx, was measured in extended birds using a flexible tape with a precision of 1 mm, and expressed relative to BW. Tarsus length was also determined using a digital caliper and expressed relative to BW.

Statistical Analysis

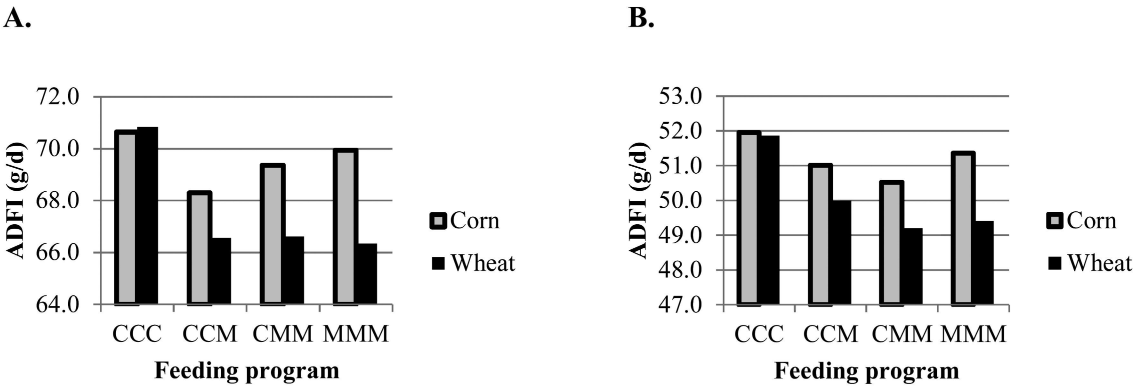
Data were analyzed with a completely randomized design with 8 treatments arranged as a 2 × 4 factorial with 2 main cereals, and 4 feeding programs, that differed in the form of the feeds used during the 3 periods of the rearing phase. Main effects and their interactions were analyzed using the GLM procedure of SAS (SAS Institute, 2004). The experimental unit was the cage for all traits. Results in the tables are presented as least-square means and differences were considered significant at $P < 0.05$. When the model was significant, treatment means were separated using the Tukey test.

RESULTS

The chemical analyses of the experimental diets are shown in Table 2. The GMD of the corn and wheat mash diets was lower from 0 to 5 wk (735 and 799 μm) than from 5 to 10 wk (1,204 and 1,204 μm) or from 10 to 17 wk (1,118 and 1,199 μm) of age. Also, the GMD of the corn and wheat diets in crumble form was lower from 0 to 5 wk (1,255 and 1,295 μm) than from 5 to 10 wk (1,792 and 1,741 μm) or from 10 to 17 wk (1,734 and 1,645 μm) of age.

Growth Performance

From 0 to 10 wk of age, no interactions between main cereal and feed form of the diet were detected for any trait. However, from 10 to 17 wk of age, ADFI was similar in pullets fed diets based on corn or wheat in crumbles continuously (0 to 17 wk) but not in pullets that received the diets in mash form in any of the previous feeding periods ($P < 0.01$ for the interaction; Figure 1A). From hatch to 17 wk of age, pullets fed corn had greater ADFI than pullets fed wheat (51.2 vs. 50.1 g; $P < 0.001$) with most of the differences observed after 5 wk of age (57.4 vs. 56.5 g from 5 to 10 wk; $P < 0.01$ and 69.6 vs. 67.6 g from 10 to 17 wk; $P < 0.001$) (Table 3). Consequently, from hatch to



	CCC[1]	CCM[2]	CMM[3]	MMM[4]
Corn	70.6^{a,b}	68.3^{b,c}	69.4^{a,b}	69.9^{a,b}
Wheat	70.8^{a}	66.6^{c}	66.6^{c}	66.3^{c}

	CCC	CCM	CMM	MMM
Corn	52.0^{a}	51.0^{a,b,c}	50.5b	51.4^{a,b}
Wheat	51.9^{a,b}	50.0^{c,d}	49.2^{d}	49.4^{d}

[1]CCC = crumbles from 0 to 17 wk.
[2]CCM = crumbles from 0 to 10 wk followed by mash to 17 wk.
[3]CMM = crumbles from 0 to 5 wk followed by mash to 17 wk.
[4]MMM = mash from 0 to 17 wk.
[a-b-c-d]Means without a common superscript differ significantly.

Figure 1. Influence of the main cereal and feed form of the diet on (A) ADFI from 10 to 17 wk of age ($P = 0.007$ for the interaction and SD = 1.66) and (B) ADFI from 0 to 17 wk of age ($P = 0.028$ for the interaction and SD = 0.92).

Table 3. Influence of the main cereal and feed form of the diet on growth performance of brown-egg pullets from 0 to 17 wk of age.[1]

	0–5 wk			5–10 wk			10–17 wk			0–17 wk		
Treatment	ADFI (g)	ADG (g)	FCR[4]	ADFI	ADG	FCR	ADFI	ADG	FCR	ADFI	ADG	FCR
Cereal												
Corn	19.3	8.77^{b}	2.21^{a}	57.4^{a}	16.7	3.45^{a}	69.6^{a}	10.5^{a}	6.62	51.2^{a}	11.8	4.33^{a}
Wheat	19.2	9.20^{a}	2.09^{b}	56.5^{b}	16.7	3.39^{b}	67.6^{b}	10.2^{b}	6.67	50.1^{b}	11.8	4.25^{b}
Feeding program[2]												
CCC	19.1^{b}	9.18^{a}	2.09^{b}	58.3^{a}	17.3^{a}	3.38^{b}	70.7^{a}	11.0^{a}	6.41^{b}	51.9^{a}	12.3^{a}	4.21^{c}
CCM	18.9^{b}	9.12^{a}	2.08^{b}	58.4^{a}	17.2^{a}	3.39^{b}	67.4^{b}	9.7^{c}	6.96^{a}	50.5^{b}	11.8^{b}	4.30^{a,b}
CMM	18.8^{b}	9.19^{a}	2.05^{b}	55.5^{b}	16.1^{b}	3.45^{a}	68.0^{b}	10.2^{b,c}	6.68^{a,b}	49.9^{b}	11.6^{b}	4.29^{b}
MMM	20.2^{a}	8.46^{b}	2.39^{a}	55.7^{b}	16.1^{b}	3.45^{a}	68.1^{b}	10.5^{b}	6.52^{b}	50.4^{b}	11.5^{b}	4.36^{a}
SD[3]	0.55	0.293	0.089	1.29	0.47	0.071	1.66	0.56	0.337	0.92	0.28	0.083
						Probability						
Cereal	0.39	<.001	<.001	0.006	0.66	<.001	<.001	0.006	0.50	<.001	0.84	<.001
Feeding program	<.001	<.001	<.001	<.001	<.001	0.001	<.001	<.001	<.001	<.001	<.001	<.001
Cereal x feeding program	0.71	0.54	0.14	0.74	0.93	0.74	0.007	0.34	0.96	0.028	0.68	0.36

[a,b]Means with different superscripts in the same column within each main effect or the interaction are significantly different ($P < 0.05$).

[1]Only main effects are shown. The significant interaction detected (for ADFI from 10 to 17 wk and from 0 to 17 wk of age) are shown in Figure 1.

[2]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[3]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 17, 15, or 13 pullets each from 0 to 5 wk, 5 to 10 wk, and 10 to 17 wk of age, respectively.

[4]Feed conversion ratio.

17 wk of age, pullets fed wheat had better FCR than pullets fed corn (4.25 vs. 4.33; $P < 0.001$) with most of the benefits observed from 0 to 5 wk of age (2.09 vs. 2.21, respectively; $P < 0.001$). ADG, however, was not affected by the main cereal of the diet. BW uniformity was not affected by the main cereal of the diet at any age (Table 4).

From hatch to 17 wk of age, ADG was greater in pullets fed crumbles continuously than in pullets fed any of the other treatments (12.3, 11.8, 11.6, and 11.5 g

Table 4. Influence of the main cereal and feed form of the diet on BW uniformity of the pullets.[1]

Treatment	5 wk	10 wk	17 wk
Cereal			
Corn	10.1	7.4	6.3
Wheat	10.1	7.3	6.3
Feeding program[2]			
CCC	9.8	7.6	6.4
CCM	9.8	7.2	6.1
CMM	9.8	6.8	6.4
MMM	11.1	7.8	6.4
SD[3]	1.80	1.44	1.38
	Probability[4]		
Cereal	0.89	0.79	0.89
Feeding program	0.059	0.18	0.89

[1]Uniformity presented as the CV of pullets BW per replicate (Peak et al., 2000).

[2]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[3]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 17, 15, or 13 pullets each from 0 to 5 wk, 5 to 10 wk, and 10 to 17 wk of age, respectively.

[4]The interactions between cereal and feed form were not significant ($P > 0.05$).

for pullets fed crumbles from 0 to 17 wk, switched from crumbles to mash at 10 or 5 wk of age, or fed mash continuously; $P < 0.001$). Consequently, FCR was better in pullets fed crumbles continuously than in pullets fed mash continuously, with pullets fed the other 2 treatments being intermediate (4.21, 4.36, 4.29, and 4.30, respectively; $P < 0.001$). In all periods considered (0 to 5 wk, 5 to 10 wk, and 10 to 17 wk of age), crumble feeding improved ADG ($P < 0.001$) and FCR ($P < 0.001$) as compared with mash feeding. From 5 to 10 wk of age, pullets that were switched from crumbles to mash feeding at 5 wk of age had similar ADFI, ADG, and FCR to pullets that were fed mash continuously from 0 to 10 wk of age. Similarly, from 10 to 17 wk of age, pullets switched from crumbles to mash diets at 10 wk of age had similar ADFI, ADG, and FCR to pullets switched to mash at 5 wk of age. At 5 wk of age, pullets fed crumbles tended to have better BW uniformity than pullets fed mash (9.8 vs. 11.1%; $P = 0.06$) but no differences were detected at 10 and 17 wk (Table 4).

Gastrointestinal Tract Traits

No interactions between main cereal and feed form of the diets were detected for any of the GIT traits measured at any age and therefore only main effects are presented. At 5 and 10 wk of age, the RW of the GIT was not affected by the main cereal of the diet but at 17 wk of age, the GIT was heavier (12.2 vs. 11.7%; $P < 0.001$) in pullets fed corn than in pullets fed wheat (Table 5). The RW of the gizzard was higher at all ages in pullets fed corn compared to pullets fed wheat, with differences being significant at 5 wk (4.9 vs. 4.6%; $P < 0.01$) and 17 wk (4.1 vs. 3.7%; $P < 0.001$) of age (Table 6). Also, the digesta content of the gizzard at 17 wk of age, was greater (26.3 vs. 24.5%; $P < 0.05$) in pullets fed corn than in pullets fed wheat. However, gizzard pH and the RL of the SI and the ceca were not affected by the main cereal of the diet at any age (Tables 6 and 7).

Feed form affected the RW of the GIT and gizzard at all ages (Tables 5 and 6, respectively). At 17 wk of age, pullets fed mash continuously had heavier GIT (12.7 vs. 11.0%; $P < 0.001$) and gizzards (4.4 vs. 2.9%; $P < 0.001$) than pullets fed crumbles continuously, with pullets fed the other 2 treatments being intermediate. Similar results were observed at 5 and 10 wk of age. When pullets were switched from crumble to mash feeding at 5 or 10 wk of age, the RW of the GIT and gizzard increased. In fact, at 10 and 17 wk of age, the RW of both organs were similar for all the pullets that were fed mash feeds in any of the previous periods (0 to 5 wk, 5 to 10 wk, or 0 to 10 wk of age). At 17 wk of age, the RW of the GIT and gizzard of pullets switched from crumbles to mash feeding at 5 or 10 wk of age, were intermediate between those of pullets that were fed crumbles or mash continuously ($P < 0.001$). Also at this age, the digesta content of the gizzard was lower in pullets fed crumbles continuously than in pullets that were fed mash in any of the 3 feeding periods considered (17.3, 27.8, 29.0, and 27.6% for pullets fed crumbles from 0 to 17 wk, 0 to 10 wk, and 0 to 5 wk of age, or fed mash continuously; $P < 0.001$). Similar results, with lower gizzard digesta content for pullets fed crumbles than for pullets fed mash, were observed at 5 and 10 wk of age. When pullets were switched from crumbles to mash feeds at any age, gizzard digesta content increased to levels similar to those of the pullets fed mash continuously (Table 6). Gizzard pH responded quickly to changes in feed form; pullets switched from crumbles to mash feeding at 5 or 10 wk of age showed in the next control (10 or 17 wk of age, respectively) a pH similar to that of pullets that were fed mash continuously. In fact, at 17 wk of age, gizzard pH was higher in pullets fed crumbles from 0 to 17 wk than in pullets that received mash in any of the 3 feeding periods considered (3.88, 3.26, 3.11, and 3.17, for pullets fed crumbles from 0 to 17 wk, 0 to 10 wk, or 0 to 5 wk of age, or fed mash continuously; $P < 0.001$).

The SI and the ceca were longer in pullets fed mash than in pullets fed crumbles at any age but the differences tended to be significant only for the SI at 5 wk (323 vs. 317 cm/kg BW; $P = 0.065$) and 10 wk (126 vs. 124 cm/kg BW; $P = 0.095$) of age (Table 7). Most of the differences in the lengths of the SI were detected for the duodenum and jejunum. The RL of the SI and ceca re-adapted quickly to changes in feed form, following a similar pattern to those described for the RW of the GIT and the gizzard.

Table 5. Influence of the main cereal and feed form of the diet on BW (g) and the relative weight (% BW) of the gastrointestinal tract (GIT) of the pullets.

Treatment	5 wk		10 wk		17 wk	
	BW	GIT[1]	BW	GIT	BW	GIT
Cereal						
Corn	329	21.2	930	14.7	1,314	12.2[a]
Wheat	335	20.9	947	14.8	1,339	11.7[b]
Feeding program[2]						
CCC	337[a]	20.5[b]	968[a]	14.0[b]	1,374[a]	11.0[c]
CCM	344[a]	20.5[b]	969[a]	14.0[b]	1,321[a,b]	11.9[b]
CMM	333[a,b]	21.0[a,b]	909[b]	15.3[a]	1,307[b]	12.3[a,b]
MMM	314[b]	22.2[a]	907[b]	15.7[a]	1,304[b]	12.7[a]
SD[3]	22.5	1.44	54.0	0.81	61.50	0.66
			Probability[4]			
Cereal	0.25	0.32	0.17	0.26	0.092	0.002
Feeding program	0.010	0.010	0.001	0.001	0.003	0.001

[a–c]Means with different superscripts in the same column within each main effect are significantly different ($P < 0.05$).

[1]Weight of the digestive tract (from the beginning of the proventriculus to cloaca), including digesta contents, spleen, gizzard, liver, and pancreas.

[2]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[3]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 2 pullets each.

[4]The interactions between cereal and feed form were not significant ($P > 0.05$).

Table 6. Influence of the main cereal and feed form of the diet on the relative weight (% BW) of the full gizzard, gizzard digest content (% full gizzard weight), and gizzard content pH of the pullets.[1]

Treatment	5 wk			10 wk			17 wk		
	Weight	Content	pH	Weight	Content	pH	Weight	Content	pH
Cereal									
Corn	4.9[a]	30.9	3.33	4.0	25.3	3.27	4.1[a]	26.3[a]	3.31
Wheat	4.6[b]	29.3	3.21	3.9	25.4	3.20	3.7[b]	24.5[b]	3.40
Feeding program[2]									
CCC	4.3[b]	29.2[b]	3.43[a]	3.1[b]	20.0[b]	3.84[a]	2.9[c]	17.3[b]	3.88[a]
CCM	4.3[b]	28.7[b]	3.35[a]	3.0[b]	18.4[b]	3.71[a]	3.9[b]	27.8[a]	3.26[b]
CMM	4.6[b]	28.4[b]	3.38[a]	4.8[a]	31.1[a]	2.71[b]	4.3[a]	29.0[a]	3.11[b]
MMM	5.8[a]	34.1[a]	2.92[b]	5.0[a]	31.9[a]	2.68[b]	4.4[a]	27.6[a]	3.17[b]
SD[3]	0.54	5.10	0.345	0.45	4.14	0.381	0.36	3.57	0.468
					Probability[4]				
Cereal	0.008	0.20	0.16	0.34	0.86	0.47	0.001	0.034	0.39
Feeding program	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001

[a,b]Means with different superscripts in the same column within each main effect are significantly different ($P < 0.05$).

[1]The BW of the pullets is shown in Table 5.

[2]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[3]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 2 pullets each.

[4]The interactions between cereal and feed form were not significant ($P > 0.05$).

Body and Tarsus Length

No interactions between main cereal and feed form of the diet were detected for body length or tarsus length at any age and therefore only main effects are presented (Table 8). Pullets fed corn were longer at all ages than pullets fed wheat, with the differences tending to be significant at 5 wk (118.4 vs. 115.4 cm/kg BW; $P = 0.06$) and 17 wk (48.9 vs. 48.1 cm/kg BW; $P = 0.08$) of age. Tarsus length was also longer at all ages in pullets fed corn than in pullets fed wheat, but the differences were not significant.

At 17 wk of age, pullets fed crumbles continuously were shorter ($P < 0.01$) and had a shorter tarsus ($P < 0.05$) than pullets fed mash continuously. Similar results were observed at 5 and 10 wk of age. Body and tarsus length responded quickly to changes in feed form, with increases in RL as the pullets were switched

Table 7. Influence of the main cereal and feed form of the diet on the relative length (cm/ kg BW) of the organs of the gastrointestinal tract of the pullets.[1]

	5 wk					10 wk					17 wk				
Treatment	Duod[2]	Jejun[3]	Ileum	SI[4]	Ceca	Duod	Jejun	Ileum	SI	Ceca	Duod	Jejun	Ileum	SI	Ceca
Cereal															
Corn	30.6	161	132	323	33.4	11.3	64.3	50.7	126	13.7	7.9	46.8	37.9	93	12.7
Wheat	30.5	159	128	317	33.1	11.1	63.3	49.9	124	13.5	7.6	47.1	37.7	92	12.8
Feeding program[5]															
CCC	30.8^{a,b}	157	128	315	32.9	10.7^{b}	61.6^{b}	49.0	121	13.2	7.5	44.7^{b}	36.7	89	12.6
CCM	29.2^{b}	155	127	311	32.4	10.9^{a,b}	62.1^{a,b}	50.2	123	13.4	7.8	46.9^{a,b}	37.5	92	12.6
CMM	30.0^{a,b}	159	130	319	33.1	11.7^{b}	65.6^{a,b}	50.3	128	13.9	7.9	47.5^{a,b}	38.2	94	12.8
MMM	32.3^{a}	168	136	336	34.6	11.5^{a,b}	66.0^{a}	51.7	129	13.9	7.7	48.7^{a}	38.8	95	13.1
SD[6]	3.00	15.6	13.9	31.2	3.21	1.02	4.98	5.16	9.9	1.14	0.90	4.05	4.11	8.1	1.05
							Probability[7]								
Cereal	0.98	0.61	0.22	0.42	0.70	0.23	0.36	0.54	0.37	0.44	0.28	0.76	0.78	0.91	0.63
Feeding program	0.024	0.066	0.24	0.095	0.21	0.007	0.013	0.49	0.065	0.17	0.63	0.038	0.44	0.13	0.51

[a,b]Means with different superscripts in the same column within each main effect are significantly different ($P < 0.05$).

[1]The BW of the pullets is shown in Table 5.

[2]Duodenum.

[3]Jejunum.

[4]Small intestine (duodenum, jejunum, and ileum).

[5]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[6]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 2 pullets each.

[7]The interactions between cereal and feed form were not significant ($P > 0.05$).

Table 8. Influence of the main cereal and feed form of the diet on the relative length (cm/kg BW) of the pullets and the tarsus.[1]

	5 wk		10 wk		17 wk	
Treatment	Pullet[2]	Tarsus[3]	Pullet	Tarsus	Pullet	Tarsus
Cereal						
Corn	118.4	18.5	62.4	7.6	48.9	6.5
Wheat	115.4	18.1	61.5	7.5	48.1	6.4
Feeding program[4]						
CCC	115.6^{b}	17.9^{b}	60.5^{b}	7.4^{b}	47.0^{b}	6.2^{b}
CCM	114.2^{b}	17.9^{b}	60.7^{b}	7.4^{b}	48.9^{a}	6.4^{a,b}
CMM	116.1^{a,b}	18.3^{a,b}	63.2^{a}	7.7^{a,b}	49.0^{a}	6.5^{a,b}
MMM	121.7^{a}	19.0^{a}	63.4^{a}	7.7^{a}	49.1^{a}	6.5^{a}
SD[5]	6.48	1.05	2.73	0.39	1.74	0.36
			Probability[6]			
Cereal	0.056	0.11	0.18	0.16	0.076	0.87
Feeding program	0.005	0.008	0.010	0.004	0.009	0.020

[a,b]Means with different superscripts in the same column within each main effect are significantly different ($P < 0.05$).

[1]The BW of the pullets is shown in Table 5.

[2]Measured from the tip of the beak to the end of the longest phalanx.

[3]Measured with a caliper above the spur.

[4]CCC = crumbles from 0 to 17 wk; CCM = crumbles from 0 to 10 wk followed by mash to 17 wk; CMM = crumbles from 0 to 5 wk followed by mash to 17 wk; MMM = mash from 0 to 17 wk.

[5]36 replicates for the main cereal, 18 replicates for feed form, and 9 replicates for the interaction, with of 2 pullets each.

[6]The interactions between cereal and feed form were not not significant ($P > 0.05$).

from crumbles to mash feed, following a similar pattern to those described for the RW of the GIT and the gizzard and for the RL of the SI and ceca.

DISCUSSION

Within each feeding period, the gross energy, crude protein, ether extract, and ash content of the mash and crumbles diets were similar to calculated values, indicating that the ingredients were mixed correctly. The GMD of the diets fed from 0 to 5 wk of age was smaller than that of the diets fed from 5 to 10 wk or 10 to 17 wk of age, consistent with the smaller size of the screen used to grind the cereals for the starter feeds. Within each feeding period, the GMD was not affected by the main cereal of the diet.

Growth Performance

From 0 to 17 wk of age, feed intake was reduced, and FCR was improved, in pullets fed wheat as compared with pullets fed corn but ADG was not affected. Published data comparing wheat and corn in poultry diets, however, are conflicting with reports showing better (Frikha et al., 2009a; Kiarie et al., 2014), similar (Frikha et al., 2011; Pérez-Bonilla et al., 2011), or reduced (Mathlouthi et al., 2002; Amerah et al., 2008; Abdollahi et al., 2013b) performance with wheat. The reasons for the discrepancies are unknown but might be related to the variability in the physico-chemical characteristics of the cereals (Gutiérrez-Álamo et al., 2008; Pérez-Bonilla et al., 2011). Wheat in Spain is produced on non-irrigated land and consequently, its chemical composition and nutritive values vary depending on climate conditions. In addition, wheat contains a high and variable amount of pentosans and β-glucans, which increase digesta viscosity and reduces productive performance in poultry (Lázaro et al., 2003a; Mirzaie et al., 2012). NSP enzymes reduce digesta viscosity and improve nutrient digestibility in birds fed diets with a high NSP content (Lázaro et al., 2003b, 2004; García et al., 2008). Consequently, differences in performance between birds fed diets based on corn or wheat might be reduced, or even disappear, when the feeds are supplemented with adequate enzymes. Moreover, in the current research, the NSP enzyme supplementation increased the AME_n content of the wheat by 2% (FEDNA, 2010). It is probable the enzymes used in the current research increased the utilization of the energy contained in the wheat more than expected (Lázaro et al., 2003a). However, the DM content of the corn is variable depending on the drying process, which will affect its AME_n content. Consequently, the effects of the main cereal of the diet on ADFI and FCR will depend on the source and characteristics of the particular batch of grain, as well as on the type of NSP enzyme complex used.

From hatch to 5 wk of age, pullets fed crumbles had lower ADFI than pullets fed mash, but an opposite effect was observed from 5 to 17 wk of age. The reason for the contrasting effects on ADFI between crumbles and mash during these 2 periods is not known. Feed wastage could not be measured in this research and consequently, feed refusal was considered to be a part of voluntary feed intake. It is probable that feed wastage was higher in pullets fed mash than in pullets fed crumbles during the early stages of life, but not thereafter, as has been reported in broilers by Serrano et al. (2013) and Abdollahi et al. (2013a). This suggestion is consistent with the greater BW and better FCR recorded in the starter period for pullets fed crumbles as compared with pullets fed mash, in spite of the reduced "apparent" ADFI.

The beneficial effects of feeding crumbles or pellets on growth performance are well documented in broilers (Abdollahi et al., 2013b; Jiménez-Moreno et al., 2015) but not in pullets. In the current research, pullets fed crumbles showed a 6.6% greater ADG and 11.5% better FCR from 0 to 5 wk than pullets fed mash. From 0 to 17 wk of age, the advantages of feeding crumbles continuously over feeding mash continuously were reduced (4.2% for ADG and 3.0% for FCR) but still of considerable practical interest. Guzmán et al. (2015) reported that pullets fed crumbles from hatching to 5 wk of age had 6.5% greater ADG and 8.2% better FCR than pullets fed mash, consistent with the data reported herein. Frikha et al. (2009b) reported 2.8% heavier weights at 6 wk of age in pullets fed 2 mm pellets compared to pullets fed mash, but in this research no differences were detected for FCR. Gous and Morris (2001) reported that pullets fed crumbles from 0 to 4 wk of age, and then pellets from 5 to 20 wk, had 6% better ADG and 7.5% better FCR from 0 to 20 wk of age than pullets fed mash continuously. Saldaña et al. (2015) reported that pullets fed crumbles had 9.1% higher ADG and 2.4% better FCR than pullets fed mash from hatching to 17 wk of age. In general, differences in growth reported in the literature between birds fed crumbles and mash diets are of a higher magnitude in broilers than in pullets, especially during the first 3 wk of life. For example, Serrano et al. (2013) reported 17.2% greater ADG and 4.8% better FCR with broilers fed crumbles from 1 to 25 d of age than for those fed mash diets. Also, Jiménez-Moreno et al. (2015) observed 32.6% greater ADG and 2.9% better FCR with pellets than with mash feeds from 1 to 21 d of age. Similar improvements in ADG and FCR with crumbles have been reported in broilers by Cerrate et al. (2009). Broilers are more voracious than pullets and therefore a reduction in feed particle size, as occurs when the feed is pelleted, may result in higher increases in voluntary feed intake and growth.

In the current research, ADFI was reduced any time pullets were switched from crumbles to mash feeding. In fact, pullets fed crumbles from 0 to 5 wk or from 0 to 10 wk of age had similar ADFI, ADG, and FCR in the following feeding period (5 to 10 wk or 10 to 17 wk of age, respectively) than pullets fed mash continuously. Consequently, from hatch to 17 wk of age, FCR was better in pullets fed crumbles continuously than in pullets fed mash continuously, with pullets switched from crumbles to mash feeds at 5 or 10 wk of age showing intermediate results. The data reported herein indicate that the growth pattern of the pullets re-adapts quickly to changes in feed form, as has been suggested in broilers by Mateos et al. (2012) and Svihus (2014).

Heat processing modifies the structure of the starch, protein, and fiber fraction of the cereal, facilitating nutrient digestibility and broiler growth (Gracia et al., 2003; Abdollahi et al., 2013a). However, the temperature used for pelleting the feeds in the current experiment was low (72°C for 60 s) and consequently, the heat and friction applied during the process should not have affected to a high degree the nutrient digestibility and FCR. However, feed particles are finer in pelleted than in mash feeds, and fine particles facilitate the contact and access of endogenous enzymes to nutrients improving FCR. Moreover, crumbling improves the texture and density of the feed, which might increase voluntary feed intake and reduce feed wastage.

Body weight uniformity was not affected by the main cereal or feed form of the diets at 10 or 17 wk of age, but at 5 wk, pullets fed crumbles tended ($P = 0.06$) to be more uniform, in agreement with the data of Guzmán et al. (2015). Frikha et al. (2009b), however, did not detect any effect of feed form (2 mm pellets vs. mash diets) on BW uniformity at 6 wk of age.

Gastrointestinal Tract Traits

The information available on the effects of the main cereal of the diet on GIT and gizzard weights in pullets is very scarce. In the current research, pullets fed corn had heavier GIT and gizzard at 17 wk of age than pullets fed wheat. Similar results were observed at 5 and 10 wk, but at these ages, the differences observed were not significant in most cases. Frikha et al. (2009a) reported also heavier gizzards at 6 wk of age in pullets fed corn than in pullets fed wheat, but in this research, GIT weight was not affected. In broilers, Abdollahi et al. (2013b) compared corn and wheat in diets fed as mash or pellets and reported heavier gizzards at 3 wk of age for the corn in both cases. Similar differences between corn and wheat diets have been reported by Nir et al. (1994a) with mash diets, and by Amerah et al. (2008) with pelleted diets. The heavier GIT and gizzards in broilers fed corn than in broilers fed wheat might be related to differences in the physico-chemical characteristics of the 2 cereals. In this respect, Dombrink-Kurtzman and Bietz (1993) and Dobraszczyk et al. (2002) reported that the endosperm of dent corn is harder and more difficult to grind than the endosperm of soft wheat. Consequently, corn particles might stay for longer in the gizzard than wheat particles, resulting in greater development and larger size of the muscular layers of this organ (Jiménez-Moreno et al., 2010; Svihus, 2011; Mateos et al., 2012). In fact, in the current research, gizzard digesta content was higher in birds fed corn than in birds fed wheat at all ages (although the differences were significant only at 17 wk of age), data that are consistent with the harder endosperm of the corn. In addition, the proportion of coarse particles ($> 2{,}500$ μm) was higher for the corn than for the wheat diets, which may also increase the content and weight of the gizzard (Hetland et al., 2002; Svihus and Hetland, 2002). Gizzard pH, however, was not affected by the main cereal of the diet at any age, in agreement with data of Nir et al. (1994a) in 3-week-old broilers fed mash diets.

Type of cereal did not affect the RL of the SI or the ceca at any age, consistent with the data of Frikha et al. (2009a) in 6-week-old pullets. In contrast, Abdollahi et al. (2013b) reported that the length of the SI and ceca of 3-week-old broilers increased with wheat feeding. The reasons for the discrepancies are not known but might be related to the different physico-chemical characteristics of the grains used by the authors. In this respect, Amerah et al. (2008) reported longer SI and ceca in 3-week-old broilers fed corn when the diets were finely ground whereas no differences were detected when the diets were coarsely ground.

Feed form affected the development of the different segments of the GIT in different ways. Crumbling reduced the RW of the GIT and the gizzard and its content at all ages. The reduction in the RW of the gizzard with pellets has been well documented in broilers (Nir et al., 1994b; Amerah et al., 2007b; Abdollahi et al., 2011) but the information available for pullets is scarce. Frikha et al. (2009b) reported that feeding pellets reduced the RW of the GIT and gizzard in pullets at 6 wk of age as compared with feeding mash, data that agree with the results reported herein. Pelleting reduces feed particle size and increases transit time throughout the upper part of the GIT which may result in less digesta content and lighter gizzards as compared with mash feeding (Mateos et al., 2012; Mateos et al., 2014). Crumbling increased gizzard pH at all ages, results that agree with the data of Frikha et al. (2009a) in pullets and Serrano et al. (2013) in broilers. In contrast, Nir et al. (1995) did not observe any difference in gizzard pH in 3- or 6-week-old broilers fed pelleted or mash diets, although in this research sorghum was used as the main cereal of the diet.

Feeding crumbles reduced the RL of the SI and the ceca at all ages but the differences were not significant in most cases. Frikha et al. (2009b) reported also that feeding pellets from hatch to 6 wk of age, and then mash from 6 wk to 17 wk of age, reduced the length of the SI and ceca in pullets at 6 and 17 wk of age, although the differences detected for the ceca were not significant at 17 wk. Amerah et al. (2007b) and Abdollahi et al. (2011) reported shorter SI and ceca in 3-week-old broilers fed pellets rather than mash diets, in agreement with the results reported herein for pullets.

The size of the organs of the GIT of the pullets re-adapted quickly any time the form of the feed was switched from crumbles to mash. For example, pullets that were switched from crumbles to a mash diet at 5 wk had similar RW of the GIT at 10 wk and 17 wk of age compared to pullets that were fed mash continuously. A similar re-adaptation pattern was observed for all the other variables studied (digesta content, weight, and pH of the gizzard, and RL of SI and ceca) at 17 wk of age when the pullets were switched from crumbles to mash at 10 wk. We have not found any report on the effects of changing feed form from crumbles to mash with time on the development of the different organs of the GIT in any poultry species. In the current experiment, the RW of the GIT and gizzard, the RW of the gizzard content, and the RL of the SI increased, and gizzard pH decreased, any time pullets were switched from crumble to mash feeding. The data reported herein indicate that the GIT of the pullets responds quickly to changes in diet form, suggesting that the digestive tract re-adapts as needed, to maintain optimal bird performance (Svihus, 2014). The data show also that crumbling affects negatively the development of the GIT, whether the pullets are fed a corn or a wheat based diet.

Body and Tarsus Length

Body length and tarsus length are useful criteria to evaluate body size and to predict future performance of serin (Senar and Pascual, 1997), sparrows (Cleasby et al., 2011), broilers (Mendes et al., 2007; Van Roovert-Reijrink, 2013), and pullets (Lamazares et al., 2006; Itza et al., 2011). In the current experiment, the RL of the pullets decreased with age and tended to be higher in birds fed corn than in birds fed wheat at 5 and 17 wk of age. However, tarsus length was not affected. The authors have not found any published report on the effects of the main cereal of the diet on pullet or tarsus length to compare with the results reported herein.

Pullets fed crumbles continuously were shorter and had shorter tarsus than pullets fed mash continuously at all ages. At 10 wk of age, pullet and tarsus length were similar for pullets that were fed mash from 5 to 10 wk of age, irrespective of the form of the feed supplied from 0 to 5 wk of age. The data indicate that changes in feed form produce a quick re-adaptation of pullet body traits, following a similar pattern to that described for GIT measurements.

In summary, the main cereal of the diet did not affect ADG of the pullet from hatch to 17 wk of age and in fact, FCR was improved with wheat feeding. Consequently, up to 40% wheat supplemented with adequate NSP enzymes, can be used in substitution of corn in these diets. However, pullets fed wheat had lighter GIT and gizzard and less gizzard content than pullets fed corn, a finding that suggested that under certain circumstances, the main cereal of the diet might affect indirectly subsequent hen performance. Crumble feeding improved growth performance of the pullets but reduced the RW of the gizzard and increased gizzard pH. Pullets changed from crumble to mash feeding at different ages always respond with a reduction in growth performance, an increase in RW, and an improvement in the development of the GIT and the gizzard in the subsequent period of the rearing phase. The data demonstrate that pullets re-adapt quickly to changes in feed form with changes in GIT traits, body and tarsus length, and growth. Consequently, the effects of ingredient composition and feed form of the rearing diets on subsequent pullet performance might be less relevant than currently accepted. Further research is needed to determine how these changes may affect hen production during the subsequent laying period.

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